

Reliability Assessment of Two Militarily Relevant Occupational Physical Performance Tests

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Key words: *repetitive box lifting, obstacle course, soldiers, muscular endurance*

Mots-clés: *tâche répétitive de lever de boîte, course d'obstacles, soldats, endurance musculaire*

Abstract/Résumé

To determine the number of test sessions needed to stabilize performance on two military occupational physical tests and to assess their reliability, 10 male soldiers (22 ± 3 yrs, 183 ± 7 cm, 87 ± 8 kg) performed both an indoor 6-station obstacle course (OC) and a repetitive box-lifting task (RBLT). The OC consisted of 46 cm-high hurdles, zigzag sprint, low crawl, horizontal pipe shimmy, 1.4 m wall traversal, and straight sprint. The RBLT required subjects to lift 20.5 kg boxes, continuously for 10 minutes, from the ground onto 1.3 m high platforms positioned 2.4 m apart. The OC mean \pm SD times (s), for sessions 1–4 respectively, were 37.4 ± 2.2 , 35.8 ± 2.5 , 34.7 ± 2.1 , and 34.5 ± 1.7 seconds. The number of boxes lifted was 177 ± 31 , 194 ± 28 , 189 ± 32 , and 186 ± 37 for the RBLT. Performance stabilized on the 3rd session for the OC (7% improvement over first trial, $p < 0.05$) and on the 2nd session for the RBLT (9% improvement over first trial, $p < 0.05$). The intraclass correlation coefficients were 0.92 and 0.94 for the OC and RBLT, respectively. This study demonstrates that both are reliable tests, but they do require administration of 1 single-trial session of RBLT and 2 two-trial sessions of OC before highly reliable performance data are obtained.

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On a profité de l'exécution d'un parcours intérieur comprenant six stations (OC) et une tâche répétitive de lever de boîtes (RBLT) par 10 soldats (22 ± 3 ans, 183 ± 7 cm, 87 ± 8 kg) afin de déterminer le nombre de séances nécessaires pour stabiliser la performance au cours de tâches militaires. Le parcours inclut les activités suivantes : course de haies à 46 cm du sol, sprint en zigzag, quadrupédie ventrale, équilibre sur un tuyau, franchissement d'un mur de 1,4 m et sprint droit. La tâche répétitive consiste à placer des boîtes de 20,5 kg sur des tablettes durant 10 minutes à 1,4 m du sol et à 2,4 m l'une de l'autre. Le temps de parcours observé pendant les séances 1 à 4 est de $37,4 \pm 2,2$ s, $35,8 \pm 2,5$ s, $34,7 \pm 2,1$ s, et $34,5 \pm 1,7$ s, respectivement. Le nombre de boîtes levées est de 177 ± 31 , 194 ± 28 , 189 ± 32 , et 186 ± 37 . En ce qui concerne le parcours, la performance se stabilise à la troisième séance (amélioration de 7 % comparativement à la première séance, $p < 0,05$) et, en ce qui concerne la tâche répétitive, la performance se stabilise à la deuxième séance (amélioration de 9 % comparativement à la première séance, $p < 0,05$). Les coefficients de corrélation intraclasse sont de 0,92 et de 0,94 pour le parcours et la tâche répétitive, respectivement. Cette étude montre que les deux tests sont fiables après une séance de familiarisation dans le cas de la tâche répétitive et après deux séances, dans le cas de la course d'obstacles avant d'obtenir des données de performance fiables.

Introduction

Quantifying performance of physical tasks is important for: 1) evaluating employees in physically demanding occupations and 2) experiments in which associations between basic abilities and performance of more complex tasks are explored. In the military, manual material handling of heavy loads and battlefield maneuvers are standard occupational tasks. Tests that quantify performance of such tasks must be reliable, as highly variable results have little meaning (Harman and Pandorf, 2000). Because motor learning (a problem-solving process whereby techniques are changed and perfected from repetition to repetition [Bernstein, 1967]) and strategy development are normally associated with the practice of physical tests, a test may have to be repeated a number of times to obtain reliable data (Hopkins et al., 2001; Jackson et al., 2001). The goal of administering test practice sessions is to enable the test subjects (or workers) to become proficient enough so that the test results are reliable and may then be used as a credible measure of their physical performance.

Soldiers are routinely required to perform repetitive manual materials handling tasks that require high levels of physical fitness. For example, operation of a field-artillery gun requires carrying, lifting and loading 45 kg artillery shells over long periods (Sharp et al., 1994). Combat support roles and peacekeeping missions also involve periods of intense lifting of materials such as sandbags, supplies, medical equipment, food, and tools. Laboratory measures of repetitive box lifting ability have been shown to correlate highly with various measures of muscular strength and power (Kraemer et al., 1998; Rayson et al., 2000; Sharp et al., 1993), as well as local muscular endurance and aerobic capacity (Kraemer et al., 1998). Kraemer et al. (1998) also showed that repetitive box lifting scores relate to speed of load carriage, another common and important task performed by soldiers (Pandorf et al., 2002). On the modern battlefield, the soldier may also be required to successfully negotiate obstacles in order to engage or evade the enemy. In the

laboratory, an obstacle course can be used to simulate the impediments to soldier movement that might be found in urban or rural settings. Obstacle course speed has been shown to relate to such fitness components as upper and lower body aerobic and anaerobic power, muscular strength and endurance (Bishop et al., 1999; Jette et al., 1990), and less quantifiable attributes such as agility and technique (Bishop et al., 1999).

Repetitive box lifting tests have been used in previous experiments to evaluate the effects of occupationally oriented exercise training programs (Harman et al., 1997; Knapik et al., 1996; Nindl et al., 1998; Sharp et al., 1993; Williams et al., 1999), and obstacle courses are popular tests of physical ability (Bishop et al., 1999). The repeatability of such tests has not always been established before their use. However, in order to yield acceptable measures of evaluation, such tests should be both valid and reliable. In this report, we provide test-retest reliability results for two laboratory-based tests, one measuring the time taken for obstacle course (OC) traversal and the other the number of lifts during a 10-minute repetitive box lifting task (RBLT). These two tests were studied together because they evaluate different measures of fitness that seem likely to contribute to battlefield success (Jette et al., 1989; Sharp et al., 1980; Williams et al., 1999). The purpose of this study was to determine the number of sessions needed on these tests before performance stabilized and reliable scores could be obtained.

Methods

SUBJECTS

Ten young, healthy male soldiers (22 ± 3 yrs, 1.83 ± 0.1 m, 87 ± 8 kg, 20 ± 5 %BF) volunteered for this experiment, which was approved by the Human Use Review and Scientific Review Committees at the U.S. Army Research Institute of Environmental Medicine (Natick, MA) and by the Human Subjects Research Review Board of its parent organization, the U.S. Army Medical Research and Materiel Command (Fort Detrick, MD). The investigators adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25. Subjects were medically screened, and written informed consent was obtained prior to study participation. All subjects had graduated from combat basic training and advanced individualized training within the previous 6 months. Heights were obtained with an anthropometer (GPM, Seritex, Inc., Carlstadt, NJ). Body weight was measured with an electronic floor scale (Seca, Alpha model 770, Hamburg, Germany). Body composition measurements were obtained by dual energy x-ray absorptiometry, by methods described elsewhere (Nindl et al., 2000). Dietary intake during the study was controlled by not allowing any supplement use and by requiring subjects to maintain their regular eating habits for the duration of the testing. Additionally, subjects were asked to refrain from participating in strenuous activity for the days preceding any testing.

OBSTACLE COURSE

Soldier mobility was assessed via a 6-station indoor OC that was used to simulate impediments to movement that a soldier might encounter during a conflict. Rapid navigation of the course required high levels of speed, strength, coordination, agility,

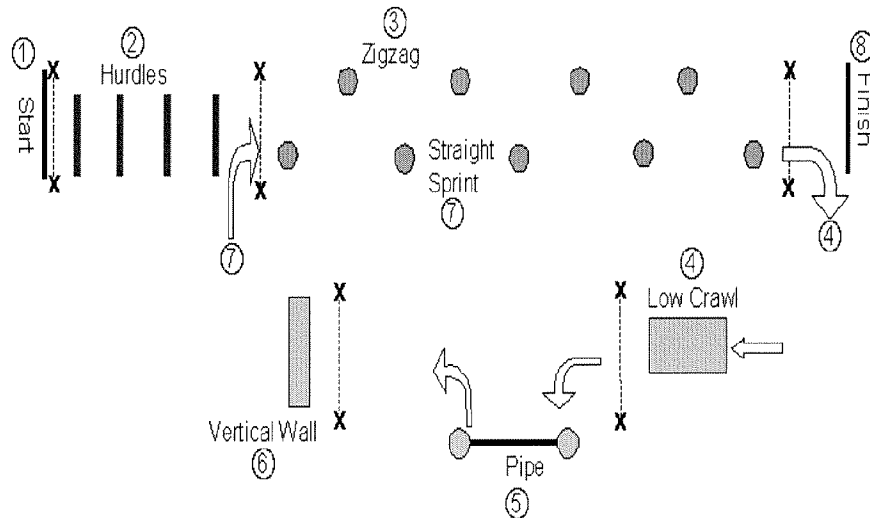


Figure 1. The layout of the indoor 6-station obstacle course. Circled numbers indicate the order of progression through the course. The X's represent placement of the light beam devices used to record timing of the event. The entire course fits into a rectangular space approximately 42 m by 10 m. A segment of the course was run through twice, first by zigzagging around cones (labeled 3) and later by sprinting between them (labeled 7). The five hurdles were 2.1 m apart. The distance from the last hurdle to the first zigzag cone was 5.5 m. The zigzag cones were staggered 1.5 m apart laterally and 3.35 m apart along the length of the course segment. A 7.9 m long U-shaped turn led to the low crawl. 5.2 m separated the low crawl from the horizontal pipe. The distance from the horizontal pipe to the vertical wall was 11.3 m. Another 5.3 m long U-shaped turn led to the final straight sprint.

and anaerobic endurance of both the lower and upper body (Bishop et al., 1999; Jette et al., 1990). Figure 1 illustrates the layout of the OC. The first obstacle was a set of five 46-cm-high plastic hurdles spaced over 16.8 m. The subjects then had to run zigzag around 9 staggered plastic cones covering a distance of 26.8 m. They then rounded a corner and low-crawled through a 3.7-m-long wood frame tunnel, 61 cm high and 91 cm wide. Upon exiting the low crawl, the volunteers shimmied along a 3.7-m-long pipe suspended 2 m above the ground, a movement requiring them to hang from the pipe upside-down, with their legs crossed around the pipe, and advance by pulling with the hands. The next obstacle was a 137-cm-high wooden wall over which the subjects climbed or bounded. Subjects finished the obstacle course by speeding around a corner and sprinting 28.7 m.

The subjects were instructed on how to complete each obstacle and given time to practice maneuvering through the various segments of the course. They then performed the obstacle course test twice (2 trials) in each session, for 4 separate sessions, with at least 15 minutes rest between trials and at least 48 hours rest between sessions. Two trials were performed during each session to eliminate any

warm-up effects associated with a single trial. Subjects were in fact faster in the second trial an average of 73% of the time. However, the fastest time of the 2 trials was used for analysis to reflect each subject's optimal performance in a given session. Times were obtained for each obstacle using a light-beam timing system with telemetry (Brower Timing Systems, Salt Lake City, UT).

REPETITIVE BOX LIFTING TASK

Manual material-handling ability was measured via the RBLT, a test of muscular and aerobic endurance that simulates loading a truck as fast as possible under a time restriction. The test required subjects to repetitively lift 20.5 kg metal boxes with side handles from the ground onto 1.3 m high platforms, continuously for 10 minutes. The heights of the platforms were the same as that of the bed of a standard military 2.5-ton truck, and two of them were positioned facing each other 2.4 m apart. The subject moved back and forth between the 2 platforms, each time lifting a box from the ground onto a platform. After each lift, technicians lowered the box to the ground positioned for the next lift onto that platform. Thus the volunteer lifted but never lowered the boxes. Subjects were instructed to lift as many times as possible during the 10-minute period. A scorekeeper recorded the number of times boxes were lifted in the 10 minutes. Subjects repeated the RBLT during 4 separate sessions, with at least 48 hours rest between sessions. Data for only 8 subjects was analyzed for the RBLT because 2 subjects were dropped from the analysis due to incomplete data.

STATISTICAL METHODS

The results were analyzed with SAS statistical software (SAS Institute Inc., Cary, NC, USA, 1999). The total number of lifts in 10 minutes was the measure of box lift performance. The subject's OC score was the shortest traversal time produced during the 2 trials of that session. Subjects' scores from the different sessions were compared using a one-way analysis of variance with repeated measures. When a session effect was detected using $p < 0.05$ as the criterion of significance, a pairwise comparison of the sessions was done using Duncan's multiple-range test to identify significant differences between sessions. Using variance estimates obtained through analysis of variance, reliability of the tests was determined using intraclass correlation coefficient (ICC) model 2, form 1 (Portney and Watkins 1993).

$$ICC(2,1) = \frac{BMS - EMS}{BMS + (k - 1)EMS + \frac{k(RMS - EMS)}{n}}$$

where BMS is the between-subject's mean square, EMS is the error mean square, RMS is the between-test sessions mean square, k is the number of test sessions, and n is the number of subjects tested. Two ICCs were calculated for each test, one before performance stabilization occurred and one after (as determined from the Duncan post-hoc test). The variance estimates needed for the ICC calculation were obtained by running separate analyses of variance for the pre- and post-stabilization trials.

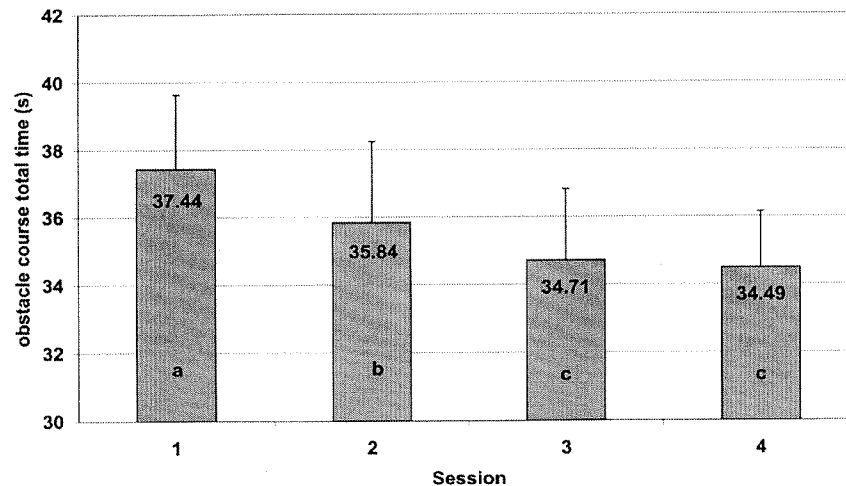


Figure 2. Mean time \pm SD (s) required to complete the indoor 6-station obstacle course. Different letters indicate significant ($P < .05$) differences.

Results

Figure 2 shows that performance on the OC, as measured by the total time, improved significantly ($p < 0.05$) by 4% from the first to the second session and 3% from the second to the third session. The intraclass correlation coefficient for these 3 sessions was 0.66. There was no further improvement in time after the third session, indicating performance had stabilized. The intraclass correlation coefficient was 0.92, for the third and fourth sessions, demonstrating a high degree of repeatability. The mean subject coefficient of variation was 4.1% across all 4 sessions on the OC. Table 1 shows the total OC times for each subject across the 4 test sessions. Table 2 shows that times for 5 of the 6 OC obstacles showed similar patterns of improvement as total course time (i.e., faster times in the third than the first session). However, just 2 of these obstacles (hurdle and low crawl) improved significantly from the first to the second session. The low crawl times were the only ones that followed the same pattern of improvement as the total times, becoming significantly faster from the second to the third session.

Figure 3 shows that performance on the RBLT improved significantly by 9% from the first session to the second session. The intraclass correlation coefficient was 0.80 for these 2 sessions. There was no further significant change after the second session, and performance in the fourth session was not statistically different from performance in either the first or second sessions. For the second, third and fourth sessions the intraclass correlation coefficient was 0.94, indicating that performance had stabilized to a high degree, signifying strong test-retest reliability. The mean subject coefficient of variation was 5.5% across the 4 sessions on the RBLT. Table 3 provides the individual data for each subject across each of the 4 sessions on the RBLT.

Table 1 Obstacle Course Times Over the Four Test Sessions

Subject	Session 1	Session 2	Session 3	Session 4
1	39.68	36.36	34.53	33.75
2	38.92	37.71	37.23	36.10
3	38.96	37.62	36.05	35.87
4	36.77	34.68	34.15	33.24
5	36.06	33.41	33.29	34.40
6	37.52	37.99	36.09	35.53
7	38.97	38.17	36.14	35.54
8	36.42	32.71	32.63	33.05
9	32.28	32.03	30.46	31.19
10	38.79	37.75	36.52	36.21

Table 2 Time (s) to Complete the Various Segments of the Obstacle Course, Mean (SD)

Session	Hurdle	Zigzag	Low crawl	Horizontal pipe	Vertical wall	Straight sprint
1	3.76 ^a (0.29)	7.82 ^a (0.45)	6.46 ^a (0.68)	9.69 ^a (1.44)	4.41 ^a (0.48)	5.29 ^a (0.32)
2	3.57 ^b (0.31)	7.65 ^{a,b} (0.41)	5.99 ^b (0.59)	9.17 ^{a,b} (1.42)	4.27 ^{a,b} (0.48)	5.20 ^a (0.31)
3	3.51 ^b (0.33)	7.51 ^b (0.45)	5.65 ^c (0.50)	8.82 ^b (1.30)	4.09 ^{b,c} (0.41)	5.17 ^a (0.28)
4	3.49 ^b (0.32)	7.44 ^b (0.56)	5.66 ^c (0.52)	8.68 ^b (0.67)	3.98 ^c (0.39)	5.24 ^a (0.24)

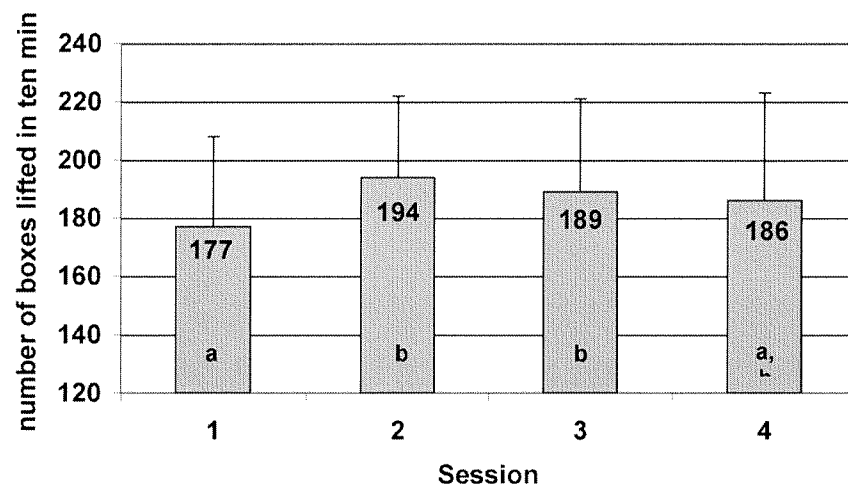
Note. Different letters indicate significantly ($p < .05$) different scores between sessions.

Discussion

Tests that simulate occupational physical performance tasks are useful in evaluating employees engaged in physically demanding occupations, such as those in the military. To be of use, such tests must have high test-retest reliability. Many factors are known to affect reliability of performance on unfamiliar tasks, including strategy development, skill improvement, motor training (that are measured before

Table 3 The Total Number of Times 20.5 kg Boxes Were Lifted During the Repetitive Box Lift Task Over the Four Test Sessions

Subject	Session 1	Session 2	Session 3	Session 4
2	135	150	145	132
3	149	176	176	167
4	219	231	230	231
5	158	198	185	206
6	205	218	224	211
7	204	216	216	218
9	190	192	183	186
10	157	167	154	138

**Figure 3.** Number of times 20.5 kg boxes were lifted in the 10-minute repetitive box lift task. Values are mean \pm SD. Different letters indicate significant ($P < .05$) differences.

any physiological adaptations take place), and motivation. In this study the task of traversing urban and rural obstacles and loading a truck with 20.5 kg boxes were simulated, respectively, via an indoor OC and a RBLT. These simulations measure somewhat different components of fitness (the correlation between OC and RBLT was $-.31$, $p > 0.45$) that are related to the ability to complete common soldier tasks and to sustain combat effectiveness (Jette et al., 1990). The findings of this experiment demonstrated, by way of higher ICCs after performance stabilization, that it

took 1 to 2 testing sessions before reliable results were obtained on these unfamiliar physical tasks.

In many previous studies, the test-retest reliability of physical performance tasks across either 2 (Bandy et al., 1993; Fulco et al., 2000; Jacobs et al., 1988) or 3 sessions of the same test (Birmingham et al., 1998; Knapik et al., 1996; Sharp et al., 1993; Steiner et al., 1993) has been examined. The current study differs from others in the literature in that measurements made from 4 separate sessions of the same test were compared, providing a more complete understanding of the amount of testing necessary before performance stabilizes.

Bishop et al. (1999) reported that OCs are largely used as training modalities to improve fitness, agility, confidence and unit cohesion. Based on the data in this report, groups can also use OC tests to reliably monitor the efficacy of interventions like fitness training for improving physical performance on the battlefield. Our OC test differed from others described in the literature in that it was of relatively short duration, and each obstacle was individually timed. Time for the low crawl portion of the OC improved the most (7% from the first to the second session and an additional 6% from the second to the third session) before performance stabilized. This suggests that strategy and skill development played a larger part in traversing this particular obstacle. For example, the subjects appeared to graduate from crawling into the tunnel to diving to the carpeted ground and sliding at least a meter using their momentum.

It is important to establish reliable baseline performance before any interventions that may alter performance are introduced. Previous studies, for example, have shown that resistance training can improve RBLT performance by 23%–40% (Harman et al., 1997; Kraemer et al., 2001; Nindl et al., 1998; Williams et al., 1999). The current study suggests that 9% of the improvement in performance on the RBLT was due to test familiarization. Therefore, since these training studies did not include repeat testing to ensure a plateau in performance, resistance training was likely responsible for improvements of 14-to-31% on the RBLT, rather than 23-40%.

In two other studies, the reliability of RBLT tests similar to the one used in this experiment has been examined. Sharp et al. (1993) reported an intraclass reliability coefficient of 0.93 for 3 trials and 0.97 for 2 trials of a 10-minute RBLT. Knapik et al. (1996) also found reliability to be high (0.97) on the second and third trials of a 10-minute RBLT. This is slightly higher than the 0.94 reported in the present study. However, our ICC includes variability over 3 sessions rather than 2. The reliability of OC performance has not been reported in the literature.

This study has highlighted the importance of having subjects practice physical tasks if repeatable results are sought. We have demonstrated that performance stabilized after 1 session of single-trial repetitive box lifting and after 2 sessions of two-trial indoor OC traversal. The longer familiarization time for the OC was perhaps due to its more complex nature, in which many skills contributed to optimal performance. In contrast, a simple repetitive movement characterized the RBLT. It may be that simple physical evaluation tests for employees, such as repetitive box lifting, require only 1 test session, while more complex tests such as the 6-station obstacle course require 2 test sessions.

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References

- Bandy, W.D., and McLaughlin, S. (1993). Intramachine and intermachine reliability for selected dynamic muscle performance tests. **J. Orthop. Sports. Phys. Ther.** 18: 609-613.
- Bernstein, N. (1967). **The coordination and regulation of movements.** Oxford, England: Pergamon Press.
- Birmingham, T.B., and Kramer, J.F. (1998). Identifying submaximal muscular effort: reliability of difference scores calculated from isometric and isokinetic measurements. **Percept. Mot. Skills.** 87: 1183-1191.
- Bishop, P.A., Fielitz, L.R., Crowder, T.A., Anderson, C.L., Smith, J.H., and Derrick, K.R. (1999). Physiological determinants of performance on an indoor military obstacle course test. **Mil. Med.** 164: 891-896.
- Fulco, C.S., Rock, P.B., Muza, S.R., Lammi, E., Cymerman, A., and Lewis, S.F. (2000). Reproducible voluntary muscle performance during constant work rate dynamic leg exercise. **Int. J. Sports. Med.** 21: 1-5.
- Harman, E., Frykman, P., Palmer, C., Lammi, E., Reynolds, K., and Backus, V. (1997) **Effects of a specifically designed physical conditioning program on the load carriage and lifting performance of female soldiers.** United States Army Research Institute of Environmental Medicine Technical Report T99-4, Natick, MA.
- Harman, E., and Pandorf, C. (2000) Principles of test selection and administration. In: T.R. Baechle and R.W. Earle (Eds.), **Essentials of strength training and conditioning** (2nd ed.), pp. 275-286. Champaign, IL: Human Kinetics.
- Hopkins, W.G., Schabert, E.J., and Hawley, J.A. (2001). Reliability of power in physical performance tests. **Sports. Med.** 31: 211-234.
- Jacobs, I., Bell, D.G., and Pope, J. (1988). Comparison of isokinetic and isoinertial lifting tests as predictors of maximal lifting capacity. **Eur. J. Appl. Physiol.** 57:146-153.
- Jackson, A.S., Atkinson, G., and Hopkins, W.G. (2001). Reliability: A crucial issue for clinicians and researchers. **Med. Sci. Sports. Exerc.** 33: S173.
- Jette, M., Kimick, A., and Sidney, K. (1989). Evaluating the occupational physical fitness of Canadian forces infantry personnel. **Mil. Med.** 154:318-322.
- Jette, M., Kimick, A., and Sidney, K. (1990). Evaluation of an indoor standardized obstacle course for Canadian infantry personnel. **Can. J. Sport. Sci.** 15:59-64.
- Knapik, J.J., and Gerber, J. (1996). **The influence of physical fitness training on the manual material-handling capability and road-marching performance of female soldiers.** US Army Research Laboratory Technical Report ARL-TR-1064, Aberdeen Proving Ground, MD.
- Kraemer, W.J., Mazzetti, S.A., Nindl, B.C., Gotshalk, L.A., Volek, J.S., Bush, J.A., Marx, J.O., Dohi, K., Gomez, A.L., Miles, M., Fleck, S.J., Newton, R.U., and Hakkinen, K. (2001). Effect of resistance training on women's strength/power and occupational performances. **Med. Sci. Sports. Exerc.** 33: 1011-1025.

- Kraemer, W.J., Nindl, B.C., Gotshalk, L.A., Harman, E.S., Volek, J.S., Tokeshi, S.A., Meth, S., Bush, J., Etzweiler, S.W., Fredman, B.S., Sebastianelli, W.J., Putukian, M., Newton, R.U., Hakkinen, K., and Fleck, S. (1998). Prediction of military relevant occupational tasks in women from physical performance components. In: S. Kumar (Ed.), **Advances in Occupational Ergonomics and Safety**, pp. 719-722. Burke, VA: IOS Press.
- Kusano, M.A., Vanderburgh, P.M., and Bishop, P. (1998). Impact of body size on women's military obstacle course performance. In: S.F. Barrett & C.H.G. Wright (Eds.), **Bio-medical Sciences Instrumentation Vol. 34. Proceedings of the 35th annual rocky mountain bioengineering symposium & 35th international ISA biomedical sciences instrumentation symposium**, pp. 357-362. Research Triangle Park, NC: ISA.
- Nindl, B.C., Kraemer, W.J., Gotshalk, L.A., Meth, S., Etzweiler, S.W., Tokeshi, S.A., Sebastianelli, W.J., Putukian, M., Newton, R.U., Hakkinen, K., and Fleck, S. (1998). The effects of resistance training on augmenting women's performance during a high-intensity military relevant manual materials handling task. In S. Kumar (Ed.), **Advances in Occupational Ergonomics and Safety**, pp 723-726. Burke, VA: IOS Press.
- Nindl, B.C., Harman, E.A., Marx, J.O., Gotshalk, L.A., Frykman, P.N., Lammi, E., Palmer, C., and Kraemer, W.J. (2000). Regional body composition changes in women after 6 months of periodized physical training. **J. Appl. Physiol.** 88: 2251-2259.
- Nindl, B.C., Sharp, M.A., Mello, R.P., Rice, V.J., Murphy, M.M., and Patton, J.F. (1998). Gender comparisons of peak oxygen uptake: repetitive box lifting versus treadmill running. **Eur. J. Appl. Physiol.** 77: 112-117.
- Pandorf, C.E., Harman, E.A., Frykman, P.N., Patton, J.F., Mello, R.P., and Nindl, B.C. (2002) Correlates of load carriage and obstacle course performance among women. **Work** 18(2), 179-189.
- Portney, L.G., and Watkins, M.P. (1993). **Foundations of clinical research: Applications to practice**. East Norwalk, CT: Appleton & Lange.
- Rayson, M., Holliman, D., and Belyavin, A. (2000). Development of physical selection procedures for the British Army. Phase 2: Relationship between physical performance tests and criterion tasks. **Ergonomics** 43: 73-105.
- Sharp, D.S., Wright, J.E., Vogel, J.A., Patton, J.F., Daniels, W.L., Knapik, J., and Kowal, D.M. (1980). **Screening for physical capacity in the U.S. Army: An analysis of measures predictive of strength and stamina**. U.S. Army Research Institute of Environmental Medicine Technical Report T 8/80, Natick, Massachusetts.
- Sharp, M.A., Harman, E.A., Boutilier, B.E., Bovee, M.W., and Kraemer, W.J. (1993). Progressive resistance training program for improving manual materials handling performance. **Work** 3: 62-68.
- Sharp, M.A., Knapik, J.J., and Schopper, A.W. (1994). Energy cost and efficiency of a demanding combined manual materials-handling task. **Work** 4:162-170.
- Steiner, L.A., Harris, B.A., and Krebs, D.E. (1993). Reliability of eccentric isokinetic knee flexion and extension measurements. **Arch. Phys. Med. Rehabil.** 74: 1327-1335.
- Williams, A.G., Rayson, M.P., and Jones, D.A. (1999). Effects of basic training on material handling ability and physical fitness of British Army recruits. **Ergonomics** 42: 1114-1124.